PART FOUR

Continuous Particulate Monitoring for $PM_{2.5}$ and PM_{10}

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1.0 Introduction

Traditional particulate monitoring uses pre-weighted filters on which particles are collected over a 24-hour period. This sampling method is labor intensive requiring an operator to pickup an exposed filter then install a new clean filter for each sample and at each sampling site. Exposed filters must then be transported back to a laboratory for conditioning, weighing, data calculation, and data entry. Samples are normally collected in a one every six day frequency (intermittent sampling). Daily sampling is possible only if multiple samplers are located at a site and still only produces a particulate concentration averaged over a 24-hour period.

In 1995 Ruppecht and Patashnick (R&P) PM_{10} TEOM® continuous monitors were installed at two sites in northern Indiana. Both sites were originally sampling PM_{10} on a daily basis using four filter-based intermittent samplers at each site with biweekly site visits. The R&P continuous monitor eliminates the need for multiple samplers at each site and provides hourly particulate concentration data as well as 24-hour averaged data.

The Ruppecht and Patashnick uses a Tapered Element Oscillating Microbalance (TEOM®) methodology to continuously measure particulate matter mass concentrations and has received U.S. EPA equivalency for PM_{10} (EQPM-1090-079).

1.1 Sampling Method Overview

Ambient air is drawn into the TEOM® sampler through an air inlet followed by an exchangeable filter cartridge, where the particulate mass collects. The inlet system is equipped with a sampling head which separates particles of either a 2.5 µm or 10 µm diameter ($PM_{2.5}$ or PM_{10}).

Sampled air proceeds through the sensor unit, which consists of a patented microbalance system. As the sample stream moves into the microbalance system, it is heated to the temperature specified by the control unit. This heating minimizes the deposition of water due to changes in ambient humidity. The control unit contains a flow controller, which regulates the sample stream through the monitor at flow rates between 0.5 and 6 liters per minute. A hollow tube is attached to a platform at its wide end (Tapered Element) and is vibrated at its natural frequency. As either $PM_{2.5}$ or PM_{10} particulate matter gathers on the filter cartridge, the tube's natural frequency of oscillation decreases. The electronic microbalance system continually monitors this frequency.

Based upon the direct relationship between mass and frequency, the instrument's microcomputer calculates the total mass accumulation on the filter, as well as the mass rate and mass concentration, in real time. The control unit contains software that allows the user to define the operating parameters of the instrumentation through menu-driven routines.

During sample collection, the program plots total mass, mass rate and mass concentration, and operating conditions on a 4-line liquid crystal display.

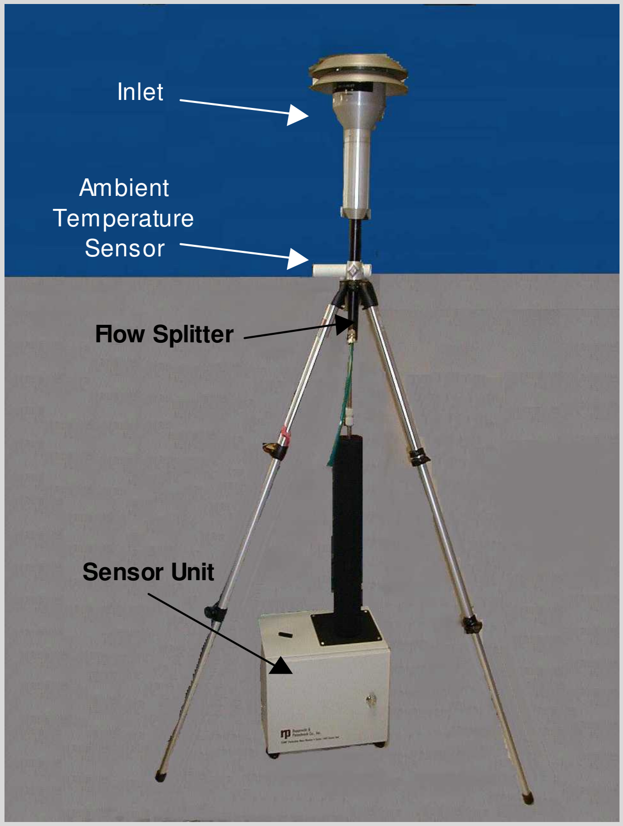

Photo 1 Monitor Components

2.0 Instrumentation

IDEM uses the R&P TEOM® monitor for all continuous particulate data collection. Table 1 applies to the R&P TEOM® Model 1400a with a standard configuration.

Table 1
Standard TEOM Configuration

Parameter	Standard Configuration
Sample Inlet Flow Rate	16.7 liters per min (1 m^3/hr)
Main Flow Rate	3 liters per min (l/min)
Sample Stream Temperature	50 °C
Particulate Matter Concentration Measurement Range	< 5 µg/m^3 to several µg/m^3
Ambient Temperature Sensor	-25 ° to 105 °C, ±2 °C accuracy
Ambient Pressure Sensor	0.68 to 1.09 atmospheres (atm)

2.1 Interferences

The R&P TEOM® primary measurement device is a microbalance system, which relies upon changes in the frequency of an oscillation tapered element to determine changes in the particle mass concentration collected. Because of this microbalance system, the instrument should be isolated from vibration and should be located in the area to be measured so that external objects are not likely to bump into the instrument enclosure or the air sampling tube. Additionally, the instrument should be located in an environment with minimal temperature fluctuations. The monitor operates effectively in environments with temperatures ranging between 7.2 and 52 °C.

The temperature of the sample stream should be maintained within as narrow of a range as possible. Large temperature fluctuations (7 to 8 °F per minute) of the sample stream may cause measurement accuracy to decrease due to the inlet system's inability to adjust the temperature of the sample to that specified by the software before traveling to the microbalance system. Sample temperature can range from ambient to 60 °C.

2.2 Instrument Description

The R&P TEOM® Series 1400a Ambient Particulate Monitor is comprised of two main components (see Photo 1): the TEOM® 1400a Control Unit and the TEOM® Sensor Unit. The following section describes the components contained in these two main units.

2.2.1 Control Unit

The control unit houses the following:

- Mass flow controllers and the control electronics for operation of the TEOM® instrument
- The main electrical and air connections to the main power supply, the auxiliary control, and the main vacuum pump connections are located on the back panel.
- The main power switch, status light, and the keypad for operating the control unit are located on the front panel. The keypad allows the user to define and adjust system parameters and functions once the software has been uploaded to the control unit. The status light flashes when there is a problem with mass flow rate, temperature, or filter loading.

2.2.2 Sensor Unit

The sensor unit houses the mass transducer sensing unit and an electronic circuit board with the appropriate wiring for electricity and frequency signal output (inside enclosure on left hand side). Located on the outside left panel are the main electric and air connections. The enclosure houses the mass transducer sensing unit, sensor unit heater, and an amplifier circuit board that processes all signals from the mass transducer.

2.2.3 Sensor/Preheater Assembly

The TEOM® sensor/preheater assembly consists of the sensor inlet and the microbalance. The sensor inlet consists of a ½" diameter metal tube. The upper end of the tube is inserted directly into the flow splitter assembly, which allows a small portion of the total flow to be drawn through the sensor unit and the remaining air sample to be drawn through the bypass line. The lower end of the sensor inlet tube is connected to the microbalance top outer wall. The connection accommodates an air temperature probe assembly that controls the temperature of the air in the inlet tube. The ½" metal tubing between the flow splitter and the sensor unit is surrounded by thick insulation to help maintain a constant temperature of the inlet air stream.

The microbalance is an insulated cylindrical enclosure that houses a metal cylinder (the sensor head) the size of the inlet tube. The metal cylinder contains an oscillating tapered element, an electronic feedback system, and a filter cartridge. The tapered element is attached to a platform at its wide end (bottom) and has a small metal tip onto which the filter cartridge sits. The electronic feedback system consists of an amplifier board, which maintains the elements oscillation, and the electronics, which allow frequency signals to be transcribed to mass units. At the bottom of the microbalance, a silicone tube, which is connected to the mass flow controller in the control unit, carries the air sample.

2.2.4 PM_{10} or $PM_{2.5}$ Inlet

A PM_{10} or $PM_{2.5}$ inlet is designed to allow only particulate matter $\leq$10 µm or $\leq$2.5 µm in diameter to remain suspended in the sample air stream as long as the flow rate of the system is maintained at 16.67 l/min. The monitor is operated in Indiana as either PM_{10} or $PM_{2.5}$ monitor.

2.2.5 Flow Splitter Assembly

The flow splitter assembly consists of two concentric hollow metal tubes. The outer tube is approximately 24" long and 1½" in diameter. The inner tube is approximately 12" long and ½" in diameter. The top of the assembly (outer tube) is configured to accommodate the PM_{10} Inlet (normal use) or the flow audit adapter (for calibration only). The lower end of the assembly consists of a pipe fitting that allows for the inner tube to enter into the outer tube and make a leak-proof connection. Also at the bottom of the flow splitter assembly is the bypass air outlet. The inner tube is connected directly to the inlet tube of the sensor unit, and the bypass air outlet is connected to the bypass air line.

The isokinetic flow splitter is used in combination with a second automatic flow controller to divide the sample flow into two components after the air steam passes through the sample inlet:

- A main flow of 3 l/min for the TEOM® mass transducer
- An auxiliary flow of 13.67 l/min that is maintained by the second flow controller. The flow splitter is located directly above the sample inlet of the TEOM® Sensor Unit.

2.2.6 Electric and Air Cable Assembly

The electric and air cable assembly is used to connect the control unit to the sensor unit.

2.2.7 Filter Cartridge

The filter cartridge is a ½" diameter thin aluminum base (foil-like) assembly. The foil is crimped around the filter edges to contain it. Attached to the aluminum base is a water resistant plastic cone that fits onto the metal tip of the oscillating element.

2.2.8 Filter Exchange Tool

The filter exchange tool is a small fork with a 4" long handle. The lower part of the tool has two perpendicular connections. The top connection is an aluminum disc that is slightly smaller than ½" in diameter, which is made to fit over the filter face when assembling and disassembling. The bottom connection is a "U-shaped" fork. The tines of the fork straddle the cone of the filter cartridge during assembling and disassembling.

Photo 2 Sensor Unit and Microbalance

2.2.9 Other Components

The TEOM® has both a coarse and fine filter located within the sensor unit to protect additional components downstream. In addition, an oil-free pump is located in this unit to provide a constant vacuum during sampling.

2.3 FDMS Series 8500 Monitor

The FDMS™ (Filter Dynamics Measurement System) Series 8500 monitor is used by the Indiana Department of Environmental Management to continuously measure $PM_{2.5}$. The Series 8500 monitor is composed of a TEOM Series 1400a Ambient Particulate Monitor loaded with FDMS software and an FDMS kit. The purpose of the FDMS kit is to provide $PM_{2.5}$ data that is equivalent to the filter-based FRM (Federal Reference Method) samplers.

Calibration and audit requirements for the FDMS are the same as the 1400a monitor. Some setup and maintenance procedures are different for the FDMS. Please refer to the FDMS Series 8500 Monitor Operating Manual for these procedures.

2.4 Ancillary Equipment

Listed below are equipment and supplies required for operation of a TEOM.

- Certified flow rate transfer standards (Bios or Chinook Streamline FTS kit)
- Certified Barometer (digital or aneroid)
- Certified thermometer (digital or liquid)
- Logbooks and database/laboratory and maintenance
- Manufacturer recommended spare parts

3.0 Site Selection

3.1 Siting Requirements

Basic siting criteria for the placement of ambient air samplers are documented in Table 2 in this section. This is not a complete listing of siting requirements; instead, an outline to be used by the operating agency to determine a sampler location. Complete siting criteria are presented in 40 CFR 58, Appendix E. All sampling locations must meet the guidelines set forth in 40 CFR Part 50 Appendix L, and Part 58 Appendix D as well as the siting guidelines outlined in Chapter 1, Section 4.0 of this manual.

As with any type of air monitoring study in which sample data are used to draw conclusions about a general population, the validity of the conclusions depends on the representativeness of the sample data. Therefore, the primary goal of a monitoring project is to select a site or sites where the collected particulate mass is representative of the monitored area.

Table 2
Example of Minimum Sampler Siting Criteria

Scale	Height Above Ground	Distance from supporting structure, meters		Other spacing criteria
		Vertical	Horizontal [a]	
Micro	2 to 7 meters	>2	>2	1. Should be >20 meters from trees.
Middle, Neighborhood, Urban, & Regional	2 to 15 meters	>2	>2	2. Distance from sampler to obstacle, such as buildings, must be twice the height that the obstacle protrudes above the sampler.
				3. Must have unrestricted airflow 270 degrees around the sampler inlet.
				4. No furnace or incineration flues should be nearby.[b]
				5. Spacing from roads varies with traffic (see (40 CFR 58, Appendix E).
				6. Sampler inlet is at least 2 m, but not greater than 4 m from any collocated PM_{10} sampler. (See 40 CFR 58, Appendix E).

[a] When inlet is located on rooftop, this separation distance is in reference to walls, parapets, or penthouses located on the roof.

[b] Distance depends on the height of furnace or incineration flues, type of fuel or waste burned, and quality of fuel (sulfur, ash, or lead content). This is to avoid undue influences from minor pollutant sources. As a precautionary measure, the sampler should be placed at least 5 meters from the furnace or incinerator flue.

3.2 Site Safety and Security

Additional factors not specified in the Code of Federal Regulations (CFR) must be considered in determining where the monitor is deployed. These factors include accessibility under all weather conditions, availability of adequate electricity, and security of the monitoring personnel and equipment. The monitor must be situated where the operator can reach it safely despite adverse weather conditions. If the monitor (or part of the monitor i.e., sample inlet) is located on a rooftop, care should be taken that the operator's personal safety is not jeopardized by a slippery roof surface during inclement weather. Consideration also should be given to the fact that routine operation (i.e., calibration, maintenance, flow check, and audit) involves transporting supplies and equipment to and from the monitoring site.

To ensure that adequate power is available, consult the manufacturer's instruction manual for the sampler's minimum voltage and power requirements. Lack of stable power source can result in the loss of data because of power interruptions.

The security of the sampler itself depends mostly on its location. Rooftop sites with locked access and ground-level sites with fences are common. In all cases, the security of the operating personnel as well as the sampler should be considered.

Photo 3 Inlet on Gary IITRI roof

4.0 Monitor Installation, Calibration, and Operation

4.1 Monitor Installation

Detailed assembly and installation procedures are contained in the instrument's manual.

4.2 Calibration of Components and Frequencies

Calibration procedures for the various components of the monitor are contained in the instrument's manual. The following section provides a list of calibrations and their recommended re-calibration frequency.

4.2.1 Overview of Calibration Procedures

Calibration of components and frequencies recommended for the instrument are as follows:

Table 3
Calibration of Components & Frequencies

Calibration	Frequency
Analog I/O	1 year
Amplifier board	1 year
Ambient air temperature	1 year
Ambient pressure	1 year
Clean air inlet system	1 year
Mass transducer	1 year
Flow controller (software)	6 months
Flow controller (hardware)	1 year

4.3 Monitor Operation

When first powered-up, the monitor is in operating mode 1. In this mode, the monitor waits until temperatures and flows have equilibrated before successively entering modes 2, 3, and 4. The monitor is fully operational in mode 4.

The S mode (Setup Mode) allows changing of operating parameters (i.e., temperature and flow rate). The X mode indicates that the normal operation of the instrument has been suspended and the monitor is "sleeping".

When in the Setup Mode (S), the user may change all of the possible system parameters. During instrument operation, on the other hand, the user is restricted to changing the values of only certain system variables.

Press <Data Stop> from any of the data collection modes (1, 2, 3, or 4) or when in the Stop All Mode (X) to enter the Setup Mode. The instrument automatically re-enters operating mode 1 if no keystrokes are entered on the keypad for 5 min when the monitor is in the Setup Mode. Otherwise, press <F1> or <Run> to re-enter operating mode 1.

[Note: The instrument enters the Stop All Mode (X) after the <Stop All> key is pressed. The Stop All Mode is meant to be an emergency mode. When the instrument resides in this mode, the flow and output to the temperature control circuits are turned off.]

Press <F1> or <Run> to reset the instrument from any operating mode. This action causes the instrument to enter operating mode 1.

Reinitialize the Instrument. The instrument operating parameters shown in this manual are the initial settings for the monitor. Re-initialization resets the instrument to its original configuration.

If the Main Screen is not displayed on the instrument, press <Main/Status> to return the monitor to the Main Screen.

Press <Data Stop> to enter the Setup Mode.

Press <Shift><Stop All> to reset the system variables to their original values.

Enter the appropriate average temperature and pressure for the sampling location.

The listing of Program Register Codes (PRC's) in Appendix A and the listing of screens in Appendix B in the Operator's Manual both contain a column entitle "Re-Init." These columns contain the new settings of each program variable after the above re-initialization routine is executed.

4.3.1 Information Shown on the Main Screen

The TEOM® Series 1400a monitor, the Main Screen is divided into two sections:

1. The status line on the top of the screen
2. The three informational lines. If the screen contains more informational lines than can be viewed at one time, pressing the <9> repeatedly makes the informational lines scroll upward. The status line always remains visible.

The Main Screen contains the most important data generated by the instrument and is the screen that is normally displayed by the monitor during operation of the unit. The status line of the main screen provides an overview of important parameters such as filter loading, the instrument status condition, various types of operational settings, and the keypad protection status. The informational lines display mass concentration results in $\mu g/m^3$ for a number of averaging times, the total mass accumulation on the filter in µg, the current system temperature and flow rates, and diagnostic indicators.

<u>Status Line on the Main Screen:</u> The status line of the Main Screen provides a quick summary of the current operational condition of the instrument. The information contained in the fields of this line is summarized below.

Status Condition: The status condition is a 1-4 number character code that summarizes the operational status of the instrument, indicating whether any exception condition exists. Whenever a status code other than "OK" is shown on the display, the instrument automatically turns on the light labeled "Check Status" on the front panel of the control unit. The status condition shown by the TEOM® Series 1400a monitor can consist of one or more codes, which are summarized in Table 2. Press <Main/Status> when the instrument is in the Main Screen to view an explanation of the current status conditions of the Status Code Screen. The <Main/Status> key toggles the instrument between the Main Screen and the Status Code Screen.

Operating Mode: The operating mode indicates the instrument's current operating setting and the type of data being computed by the monitor. An explanation of the different operating modes of the TEOM® are documented in Table 3.

Analog Output 1 Mode: The instrument normally transmits the values of three chosen variables in analog format through its three user-defined analog outputs. Analog output channel 1; however, can be defined to act in one of two different ways:

- If the "A/O 1" field of the Main Screen status line is blank, analog output 1 operates in its usual fashion.
- If a "+" appears in the A/O a field, analog output 1 is also used as status watch indicator. When defined this way, analog output 1 transmits a full-scale signal (for example, 5 VDC if the channel is configured for 0-5 VDC operation) if a status condition exists in the temperatures, flow(s), or oscillation of the mass transducer. If no such status condition exists, analog output channel 1 operates in its usual fashion. Press <F5> to toggle the "+" in the A/O 1 field.

If the filter loading percentage is high when a new TEOM® filter is placed on the mass transducer, or if the lifetime of TEOM® filter cartridges becomes noticeably shorter, this usually indicates the in-line filter in the main flow line probably needs to be exchanged.

RS-232 Mode: The RS-232 mode defines the current usage of the 9-pin RS-232 connectors on the front and back panels of the TEOM® Control Unit. The selection of the current RS-232 mode is made in the Set RS-232 Mode Screen. Alternatively, the instrument can be toggled between the None Mode (N) and Print On Line Mode (P) by pressing <F2>.

Use the supplied 9-to-9 pin RS-232 cable when connecting the instrument to an IBM AT-compatible computer with a 9-pin RS-232 connector. If the computer has a 25-pin RS-232 connector, use the 9-to-9 pin RS-232 cable in combination with the 2-to-25 pin Computer Adapter.

The 9-to-25 pin Serial Cable is designed to connect the Series 1400a monitor to a serial printer.

[Note: Never connect two serial devices to the RS-232 ports of the instrument at once, this may cause the RS-232 features of the monitor to malfunction.]

Protection: The Series 1400a monitor incorporates three states of password protection. The user has access to all capabilities of the instrument when it is unlocked (U). In the low-lock setting (L), the user is prevented from editing any of the system parameters, but may view all screens and change the operating mode of the instrument to perform such functions as filter exchange. When the monitor is in its high lock mode (H), the user cannot make any changes from the keypad, including scrolling, except for turning off the high-lock mode with the proper password.

Time: Time is displayed on the instrument in 24-h format.

<u>Informational Lines on the Main Screen:</u> The informational lines of the Main Screen show the current values of important system variables. Additional lines of information can be viewed by scrolling this display up and down. Press **<8>** to move the cursor upward and **<9>** to move it

downward. Because the Main Screen displays data computed by the instrument, none of these values can be edited by the user. The information contained in the fields of this line is summarized below.

Filter Loading: The value for filter loading indicates the fraction of the TEOM® filter cartridge's total capacity that has been used. Since this value is determined by the pressure drop of the main (sample) flow line, the instrument shows a non-zero value even if no filter is mounted in the mass transducer. New filters generally exhibit figures of 15-30%.

TEOM® filter cartridges must be exchanged before this figure reaches 100% to ensure the validity of the data generated by the instrument. At some point above 100%, the main flow drops below its set point.

When to Exchange TEOM® Filter Cartridges:

TEOM® filter cartridges must be exchanged before the figure for filter loading on the status line of the Main Screen reaches 100%. The "Check Status" light turns on and status code F is shown on the status line of the Main Screen when the filter loading percentage is greater then 90%.

4.3.2 Exchanging the Filter Cartridge

Upon arrival of a new TEOM® series 1400a Ambient Particulate Monitor, the sensor unit will not be equipped with a filter cartridge. Therefore, follow the filter exchange procedures outlined below to prepare the instrument for operation. The new instrument comes with a box of 20 blank filter cartridges. Before proceeding with the exchange, some special precautions must be taken:

- Do not handle new TEOM® filter cartridges with fingers. Use the filter tool provided with the instrument to exchange filters.
- Do not exchange filter cartridges when the TEOM® system is in the Run Mode. Filter cartridges should be exchanged either when the instrument is in the Setup Mode, Data Stop Mode, or when the instrument is turned off.
- Keep the sample pump running to facilitate filter exchange.
- Store the box of filter cartridges and filter exchange tool inside the sensor unit enclosure to provide a warm, dry, safe storage location.

4.3.3 Loading the Filter Cartridge

1. Open the door of the sensor unit.

2. Locate the horizontal handle on the TEOM® mass transducer (shown in its upward position in Photo 2). Carefully release spring clasp by pulling the horizontal lever downward. The TEOM® mass transducer then lowers into its filter changing position (see Photo 2).

[Note: When the mass transducer is in this open position, the tapered element automatically stops vibrating to facilitate filter exchange.]

3. Remove a clean filter cartridge from its shipping/storage box using the filter exchange tool. The tool's upper metal disc should cover the filter's surface, while the lower tines of the fork should straddle the hub of the filter base.

4. Hold the filter exchange tool in line with the tapered element and lightly insert the hub of the filter cartridge onto the tip of the tapered element. Ensure that the filter is seated properly. The tool's metal disc should be centered over the filter before pressure is applied. Apply downward pressure to set it firmly in place, which will reduce the chances of distorting the crimped filter.

5. Remove the filter exchange tool by retracting it sideways until it clears the filter. Do not disturb the filter.

6. Gently pull the horizontal handle upward, making sure to secure the locking pin and clasp, to close the mass transducer. Allow the springs to pull it closed for the last centimeter so that the distinct sound of metal-to-metal contact is heard.

   Do not let the TEOM® mass transducer slam closed from the full open position.

7. Close and latch the door to the TEOM® Sensor Unit. Keep the door open for as short a time as possible to minimize the temperature upset to the system.

8. If the instrument is turned on, reset it by pressing <F1> or <RUN> on the keypad of the TEOM® Control Unit.

9. After 5 min, open the sensor unit and mass transducer again. Press straight down on the filter cartridge with the bottom of the filter exchange tool. This pressure ensures that the filter cartridge is properly seated after it has experienced an increase in temperature. Then close the mass transducer and enclosure.

4.3.4 Removing the Filter Cartridge

Filter lifetime depends upon the nature and concentration of the particulate sampled. The lifetime is determined by the filter loading, as shown on the status line of the Main Screen of the TEOM® Control Unit. TEOM® filter cartridges must be exchanged when the filter loading value approaches 100%, which generally corresponds to a total mass accumulation of approximately 3 to 5 mg (about 14 to 21 days of sampling at an average PM_{10} concentration of 50 $\mu g/m^3$).

1. Open the door of the sensor unit.

2. Locate the horizontal handle on the TEOM® mass transducer. Carefully lower this handle.

   The TEOM® mass transducer then swings into its filter changing position (see Photo 2).

   When the mass transducer is in this open position, the tapered element automatically stops vibrating to facilitate filter exchange.

3. Using the filter exchange tool (see Photo 2), remove the filter cartridge from the mass transducer. Carefully insert the lower fork of the tool under the filter cartridge so that the fork straddles the hub of the filter cartridge. The tool's upper metal disc should be centered over the filter's surface, but not touching it. Gently lift the filter from the tip of the tapered element with a straight pull.

   Never twist the filter or apply sideways force to the tapered element.

4. Store the used filter or discard as necessary.

5. Use a Kimwipe® to remove any particulate from the back side of the metal disc and the tines of the fork on the filter exchange tool. During the filter removal process, the filter may be heavily loaded with particulate. When the tool comes in contact with the filter, the particulate often will transfer to the tool due to a small static charge. Cleaning the filter exchange tool will prevent any particulate from being transferred to a new filter and thus increase filter life.

6. Remove a clean filter cartridge from its shipping/storage box using the filter exchange tool. Grasp the clean filter as instructed in the previous section. Do not touch the filter cartridge with your fingers; only use the exchange tool.

7. Follow the procedures detailed in Sections 4.3.2 to insert the clean filter cartridge onto the sensor head and resort the instrument to operation mode.

Main/ STATUS	EDIT	DISP	Units	STEP SCREEN
LOCK	↑	INT	RUN	DATA STOP
←	LAST FIRST	→	NO	YES
TIME DATE	↓	A/O	RS232	STORE

F1	F2	7	8	9
F3	F4	4	5	6
F5	F6	1	2	3
F7	F8		0	CTRL
	ESC	BKSPACE	ENTER	↑ SHIFT

Figure 1 Control Unit Key Pad

5.0 Data Acquisition

Disable data logger during maintenance, calibrations, and audits.

5.1 Data Validation

Data validation criteria were developed from the instrument's operation manual recommendations and from staff's operational experience.

Table 4
Data Validation Criteria

Audit Limits and Actions	
Total Flow Rate:	
Range Limit	Action
16.67 ±1.0 l/min	Data Valid. Flow in-calibration.
> ±1.0 l/min < ±10%	Data Valid. Flow out-of-calibration, recalibrate flow.
≥ ±10% (of 16.67 l/min)	Data Invalid. Invalid period determined by either last good flow audit, last calibration, last maintenance, or last flow-related diagnostic test.
Main Flow Rate:	
Range Limit	Action
3.00 ±0.2 l/min	Data Valid. Flow in-calibration.
> ±0.2 l/min < ±10%	Data Valid. Flow out-of-calibration, recalibrate flow.
≥ ±10% (of 3.00 l/min)	Data Invalid. Invalid period determined by either last good flow audit, last calibration, last maintenance, or last flow-related diagnostic test.
Leak Check:	
Limit	Action
Main Flow ≤ 0.15 l/min	Data Valid. Pass, no action.
Main Flow > 0.15 l/min	Data Invalid. Invalid period back to last good leak check.
Aux Flow ≤ 0.60 l/min	Data Valid. Pass, no action.
Aux Flow > 0.60 l/min	Data Invalid. Invalid period back to last good leak check.
Temperature & Barometric Pressure:	
≤ ±2 °C	Data Valid. Pass, no action
> ±2 °C	Data Valid. Recalibrate temperature sensor.
≤ ±10 mmHg	Data Valid. Pass, no action
> ±10 mmHg	Data Valid. Recalibrate barometric pressure sensor.

6.0 Performance Audit Procedures

The primary goal of an auditing program is to identify problems that may result in suspect or invalid data. Performance audits should be conducted under the following guidelines:

- Audits must be done without special preparation or adjustments made to the system.
- The individual performing the audit must be someone other than the routine operator and must have a thorough knowledge of all instruments or processes being evaluated.

- All aspects of the audit must be completely documented including the types of instruments and transfer standards, model and serial numbers, calibration information, etc.

A valid 24-hour average requires 23 to 25 hours of valid data. Audits should start at the beginning of an hour or at least completed during the hour to minimize data loss.

6.1 Flow-Rate Performance Audit Procedure for Series 1400a TEOM PM_{10} Samplers

6.1.1 Audit Equipment

1. Two types of devices may be used to audit the flow rate of the instrument:
   - BIOS DryCal Flow Calibrator. This device must be used with a flow audit adaptor. The bios must be capable of measuring 3.0 l/min and 16.7 l/min to an accuracy of ±1% and having a pressure drop of less than 0.07 bar (1 psi).
   - Chinook Engineering Streamline Flow Transfer Standard (FTS) kit. The kit consists of a high flow FTS (white), a low flow FTS (black), and a digital manometer.
2. 3/8” Swagelok® plug (stainless steel or brass)
3. digital or aneroid barometer
4. digital or liquid thermometer

Some TEOM® sites have an “audit” line in place that allows the BIOS to be connected inside the shelter. The audit procedure below assumes that no audit line is installed and directs the auditor to connect the BIOS directly to the flow audit adapter.

BIOS and FTS are both acceptable audit devices, but the FTS has the advantage of working better in cold weather conditions. The following audit procedure applies to both devices. Variations between the two devices are noted below.

1. Prior to beginning the flow audit on the Series 1400a TEOM®, verify the status of the monitor. Record information in the appropriate columns of the site logbook and on the audit form.

   - Status: OK
   - Operational Mode: 4
   - Filter Loading : < 90%
   - Main Flow: ~ 3.00 LPM
   - Aux Flow: ~ 13.67 LPM
   - Noise Level : < 0.100
   - Frequency: 150 - 400

2. Disable the site data logger so that audit data is not recorded as ambient measurements. Note in the logbook and on the audit data form the start time (in military time) of the audit.

3. Reset the TEOM® Series 1400a monitor. Press the <F1> or <Run> keys on the front panel of the control unit. Any data generated by the instrument during this audit procedure is invalid.

4. Scroll the main screen using **<F>** and **<J>** until the main flow and auxiliary flow appear on the four-line display. The displayed flows are the actual volumetric flows as measured by the monitor's flow controllers. Confirm that these flows are within ±2% of their set points.

   a. main flow = 3.0 l/min 2% of 3.0 l/min = range of 2.94 to 3.06
   b. auxiliary flow =16.7 l/min 2% of 16.0 l/min = range of 16.34 to 17.00

   Any greater deviation may indicate plugged in-line filters or other blockages in the system. If this is the case, correct the condition before proceeding.

5. Access the sample inlet and remove the inlet by gently twisting and lifting.
   - BIOS; Replace the inlet with the flow audit adapter. Turn the valve of the flow audit adapter to its open position to allow for air flow.
   - FTS; Replace the inlet with the high flow white FTS.

6. Tubing connections:
   - BIOS; Use flexible tubing to connect the flow audit adapter to the vacuum (inlet) site of the BIOS.
   - FTS; Use flexible tubing to connect the electronic manometer to the side pressure port of the FTS.

7. Measure and record on the audit form the ambient temperature (°C) and ambient barometric pressure (mmHg). Allow sufficient time for the temperature probe to equilibrate to ambient conditions and ensure that the probe is not in direct sunlight or not in contact with any surfaces.

Table 5
Conversions

mmHg to atmospheres (atm)	mmHg/760
atm to mmHg	atm* 760
°C to Kelvin (K)	°C + 273

8. Audit device readings:
   - BIOS; Turn on the BIOS and allow 50 instantaneous readings before recording the average of 10 readings.
   - FTS; Turn on the electronic manometer and record the reading in inches of water. Use the formula, slope, and intercept posted on the FTS to calculate at actual conditions.

9. Observe the TEOM® display and record the auxiliary flow as the observed auxiliary flow. The volumetric flow measured by the audit flow meter must be 16.7 ± .0 l/min to be acceptable.

10. Disconnect the bypass flow line at the flow splitter. Cap the open port of the flow splitter with the 3/8" Swagelok® plug supplied with the audit kit.

11. FTS; Remove the white high flow FTS and install the black low flow FTS. Attach the electronic manometer to the side pressure port of the black FTS.

12. Observe the TEOM® display and record the main flow (nominally 3.0 l/min) on the audit flow meter. The volumetric flow indicated by the audit flow meter must be 3.0 ±0.2 l/min to be acceptable.

13. If either the Main or Auxiliary Flow is outside acceptable limits, a recalibration must be performed by the network operator.

14. Remove the cap from the flow splitter and reconnect the bypass flow line.

15. Remove audit device from sample inlet:
    - BIOS; Remove the flow audit adaptor.
    - FTS; Remove the black low flow FTS.

    Replace the inlet head by gently pushing down and twisting.

16. Return to the shelter and enable the site data logger and reset the TEOM® monitor by pressing **<F1>** or **<Run>**. The instrument begins data collection after temperatures and flow rates have remained stable at their set points for ½ hour.

17. Record the audit ending time in the site log book and on the audit sheet.

The status condition may change from OK to F, T, or both during the audit. The condition should return to OK following audit and system reset. Make sure the system goes back to OK before leaving.

6.2 Audit Data Reporting

Inform the site or network operator of the audit results as soon as possible after audit completion. A paper copy of the audit may be forwarded to the operator or personnel may view the audit in the database. If data is invalid, the auditor should promptly inform the operator verbally and in written form (memo or email).

A standard piece of field equipment for IDEM-OAQ-QAS staff is a cell phone. Immediate notification of results while the auditor is still on-site is now possible. If audit results are outside limits, the auditor while at the site should inform the network operator of the results and request instructions.

6.3 Audit Frequency

The Indiana Department of Environmental Management conducts audits of all TEOM® monitors in its network at least once each month to ensure minimal data loss.

6.4 Systems Audit

System audits are an on-site inspection and review of the total monitoring process from site location, safety, and sampling to final analysis and data reporting. System reviews are generally done at the initial set up of a network and on an annual or on an as needed basis thereafter. The specific guidelines and procedures for this type of audit are found in Chapter 15 of this manual, System Audit Criteria and Procedure for the Evaluation of Ambient Air Monitoring Networks.

7.0 Precision and Accuracy Assessment

7.1 Precision

There are no precision estimates (collocated samplers) for continuous $PM_{2.5}/PM_{10}$ samplers.

7.2 Accuracy

The accuracy of the network is measured by auditing the flow rate performance of the samplers in the network. The percentage difference between the audit flow rate and the sampler flow rate is used to determine accuracy. Two flows rates are audited on the R&P TEOM® monitor: the main flow which is approximately 3 liters per minute and the total flow which is approximately 16 liters per minute. Only the total flow is used to estimate accuracy. Accuracy calculations are described in detail in 40 CFR Part 50, Appendix L, CFR Part 50, Appendix A.

The EPA requires that 25 percent of the samplers within a reporting organization's network be audited for accuracy each quarter. To improve accuracy estimates, additional accuracy flow rate audits may be conducted each calendar quarter. IDEM-OAQ-QAS audits all continuous $PM_{2.5}/PM_{10}$ samplers in its monitoring network at least once each month. This audit frequency provides additional accuracy flow rate data and also ensures minimal data loss due to “out-of-calibration” conditions.

8.0 Maintenance

Routine preventive maintenance helps prevent failures of the monitoring processes. The overall objective is to increase measurement reliability and prevent data loss. Follow the manufacturer's recommended guidelines for routine maintenance procedures.

Maintenance records must be kept for each sampler or instrument. These records should contain a history of the sampler, including all replacement parts, suppliers, costs, installation dates, etc.

8.1 R&P Recommended Maintenance and Frequency

Table 6
Recommended Maintenance & Frequencies

Maintenance	Frequency
Clean PM_{10} or $PM_{2.5}$ inlet	When TEOM® filter cartridge is changed
Large bypass in-line filter exchange	6 months
Battery test	6 months – change if necessary
Pump test	6 months
Clean air inlet system	1 year
Rebuild piston pump	18 months

8.2 As Needed Maintenance

- Exchange fuses (7 fuses used)
- Clock adjustment
- Resetting system
- System software download

9.0 Forms

Continuous PM_{10} and $PM_{2.5}$ monitoring use the same calibration and audit forms.

Form 1
TEOM® 1400 AB Series Flow Controller Calibration Form

Site: ____________________________ Date: ________________ Initials: ___________

Monitor: ___________________________________ Last Calibration: ___________________

Calibrator: __________________________________ Last Certification: ___________________

Average Temperature Setting: _____________ °C Ambient Temperature: _______________ °C

Average Pressure Setting: ______________ atm Ambient Pressure: _________________atm

Main Flow: set main flow to 0.5 LPM = _________ LPM adj R101 until flow meter = 0.5 LPM

±0.03 LPM – adjusted to ____________LPM ____________LPM____________LPM

set main flow to 4.5 LPM – Flow Meter = ________________ LPM – adjusted R105

____________LPM ____________LPM____________LPM

set main flow back to 3.0 LPM – verify flow on flow meter: ________________ LPM

Bypass Flow: set main flow to 2.0 LPM = ________ LPM adj R201 until flow meter = 2.0 LPM
±0.2 LPM – adjusted to ____________LPM ____________LPM____________LPM

set bypass flow to 18.0 LPM – Flow Meter = ________________ LPM – adjusted R205
____________LPM ____________LPM____________LPM

set bypass flow back to 13.67 LPM – verify flow on flow meter: ________________ LPM

Leak Check: Main and Auxiliary Flow must drop below 0.15 LPM for system to be leak tight.

Main Flow = ____________ Screen
Aux. Flow = ____________ Screen

System Passed Leak Check: Y / N

Temperature Calibration: Thermometer = ______________ °C

Ambient Temp/Flow Screen: _________ °C – adjust input 8 – _________ °C

Pressure Calibration: + 10 V test point ________ DVM – adjust R304 – ________ DVM

Barometer: _________ atm – TEOM Screen _________ atm – adjust R509 _________ atm

Form 2
TEOM® PM_{10} / $PM_{2.5}$ Audit Form

Site: ____________________ Date: ______________ Initials: __________

Monitor SN: ________________________ AQS# ______________

Calibrator / FTS SN's: ______________________ Last Cert: ______________

Ambient Temperature: ________ Ambient Press: ________ ST________ ET________

________ Check if monitor is in run mode (operating mode = #4, status condition = OK)

Main Flow (Control Screen) = ______________ LPM (Set pt. = 3.0 LPM)

Main Flow + Auxiliary Flow (Control Screen) = __________ LPM (Set pt. = 16.67 LPM)

Audit Results: ** Use formula on FTS to obtain Flow Rate, Temperature in K and Pressure in atmospheres (atmospheres = mmHg/760, i.e. 745 mmHg = .980 atm) **

Main Flow (3.0 LPM ±0.2 LPM) = __________ LPM – within acceptable limits Y / N

Total Flow (16.67 LPM ±10%) = __________ LPM – within acceptable limits Y / N

Ambient Temp. Probe: TEOM®: ________ ^{o}C / Thermometer: ________ ^{o}C
(limit ±2 ^{o}C, allow time to equilibrate)

Ambient Pressure: TEOM®: ________ atm / Barometer: ________ mmHg / ______ atm
(limit ±10 mmHg or .013 atm)

Main Flow = _________ LPM (should drop below 0.60 LPM)
Aux. Flow = _________ LPM (should drop below 0.60 LPM)

*** Return Monitor to run mode following audit – press Run or F1 ***

Filter Loading % = _________ % – Filter should be changed before 80% - flow can start to drop when loading passes 90% - Data loss occurs when loading is in the 90 – 100% range.

Comments: ____

____